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An evaluation of technical progress and energy rebound effects in China's iron & steel industry

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Abstract: As a pillar industry in China, the iron & steel sector have under through rapid growth and technical progress for decades. However, energy polices aiming at energy savings may not be as good as expected due to the existence of rebound effects. The motivation of the paper is to analysis the nexus between technical progress and energy rebound effects. Based on a three-input trans-log cost function model, we first estimate the share equation and the corresponding price elasticity for each input factor. Then, the rebound effect in China's iron & steel industry over 1985-2015 is evaluated through decomposing the energy prices. Empirical results show that: (1) The price elasticities of input factors are negative; (2) Energy/capital and energy/labor show substitute relationships; (3) The average energy rebound effect in the ISI is as high as 73.88%; (4) The energy rebound effect shows a downward trend before the 11th Five-year period and then an upward trend after that. Therefore, policies proposals of lowering the rebound effect should be placed not only on technical progress, but also on energy price reform by reducing energy subsidies and thus accelerating energy price marketization, so as to promote energy substitution, reduce energy rebound effect and produce further economic and environmental benefits.

Keywords: Technical progress, Price elasticity, Energy rebound effect; China's iron & steel industry

1. Introduction

1.1 The growth of Iron & Steel Industry (ISI) in China

From the perspective of neoclassical economics, there are two types of driving forces for economic growth: one works as a contributing factor for production, including capital, labor and energy input; the other aims at improving productivity. Any economic growth path which relies on the increase of factor inputs is regarded as unsustainable in the long term. However, improvement in productivity is able to ensure the sustainability of economic growth. Technical progress is seen as an important influencing factor to total factor productivity, which would contribute to economic growth. As technical progress can enhance productivity, changes in technical level will have an impact on the growth of production in ISI. A variety of literature uses the indicator of Research and Development (R&D) expense to indicate technical level (Lin and Xie, 2013).

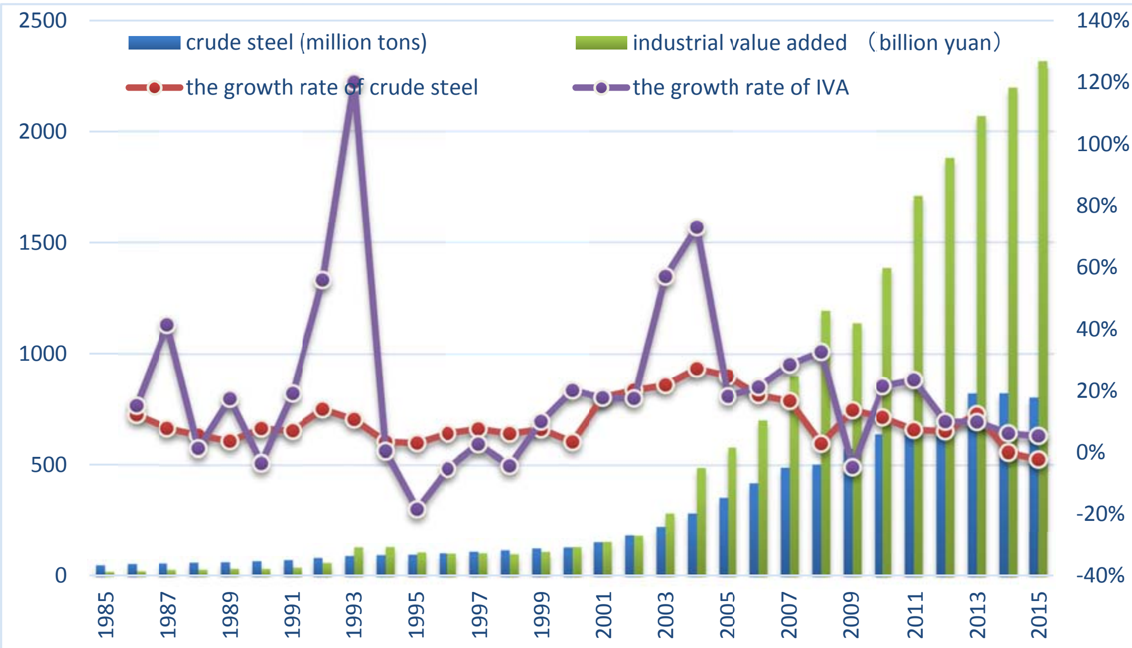

Figure 1 Production of crude steel in China's ISI

Source: China Statistical Yearbook (China Statistics Press, 1986-2016).

In past 30 years, China's ISI has been experiencing a sustainable development (see Figure 1), with a rapid growth in crude steel production and the production value represented by the Industrial Value Added (IVA). During 1985 to 2015, R&D expense in China's ISI increased significantly from 237 to 6123 million Yuan, at an average growth rate as high as 23% per annum (shown in Figure 2). The growth rate of R&D expenditure is higher than that of IVA, suggesting that the growth of this industry is the results of technical progress. In 2015, total R&D personnel was 137.8 thousand man-years (measured in full-time equivalent), taking up a proportion of 3.78% in total number of employees in the ISI, with 1.0 percent higher than that in the industrial sector. The growth of R&D expenditure and higher proportion of R&D personnel means that the technical level of ISI has been improved significantly during past 30 years.

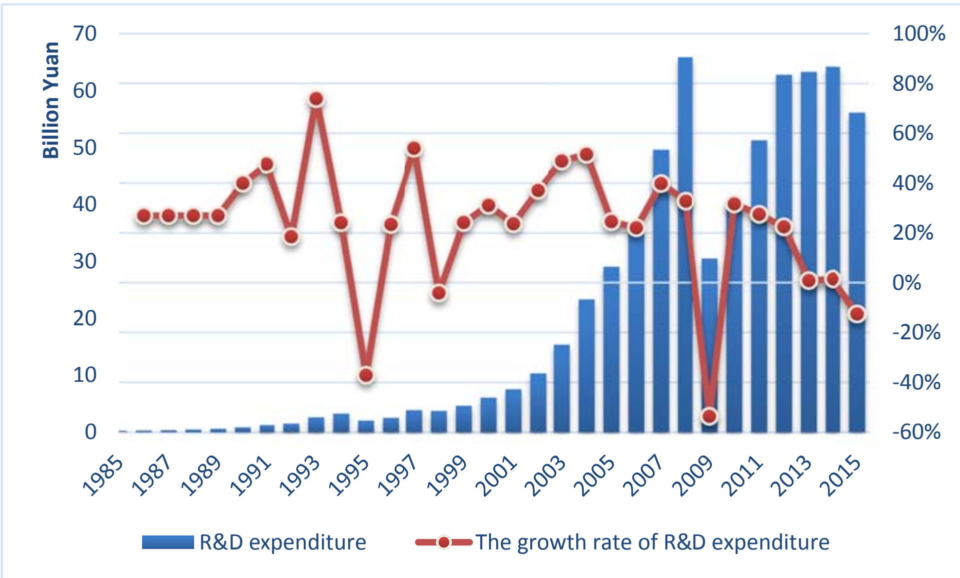

Figure 2 R&D expenditure in China's ISI

Source: China Statistical Yearbook on Science and Technology (China Statistics Press, 1986-2016).

1.2 Technical progress and energy rebound effect

Technical progress can not only lead to the growth of production, but also an improvement in energy efficiency, thus a reduction in energy inputs, which would give rise to energy savings. The contribution rate of technical process to energy savings is around 40%-50% in China's ISI (China Steel Yearbook, 2011). Significant energy savings in ISI have been achieved by measures that aiming at advanced producing routes, for example, replacing the open hearth furnaces with the electric arc furnaces; applications of more efficient ways for casting and rolling of the final crude steel product (Napp et al., 2014); etc.

Nevertheless, the amount of energy inputs in China's ISI is still large. As shown in Figure 3, energy inputs in the ISI was 76.4 mtce in 1985, then this number increased by more than eight times to 639.5 mtce in 2015. The annual growth rate of energy inputs in the ISI has been 23.1% for the past 30 years, much higher than the overall growth rate of industrial energy consumption (6.3%). As about 70% of energy recourses consumed in China are coal related, the rapid growth in energy consumption brings environmental issue inevitably.

The index of energy intensity is generally applied to represent energy efficiency. During 1985-2015, energy input per unit IVA in China's ISI has dropped by 76.2%, from 0.46 mtce per billion yuan in 1985 to 0.11 mtce per billion yuan in 2015. In contrast, the fluctuation of energy consumption per ton crude steel was relatively moderate, dropping from 1.64 to 0.80 tce/ton. Both these two indicators show apparent a decrease trend in energy intensity, suggesting that as the industrial output increases, energy efficiency in China's ISI has been improved greatly.

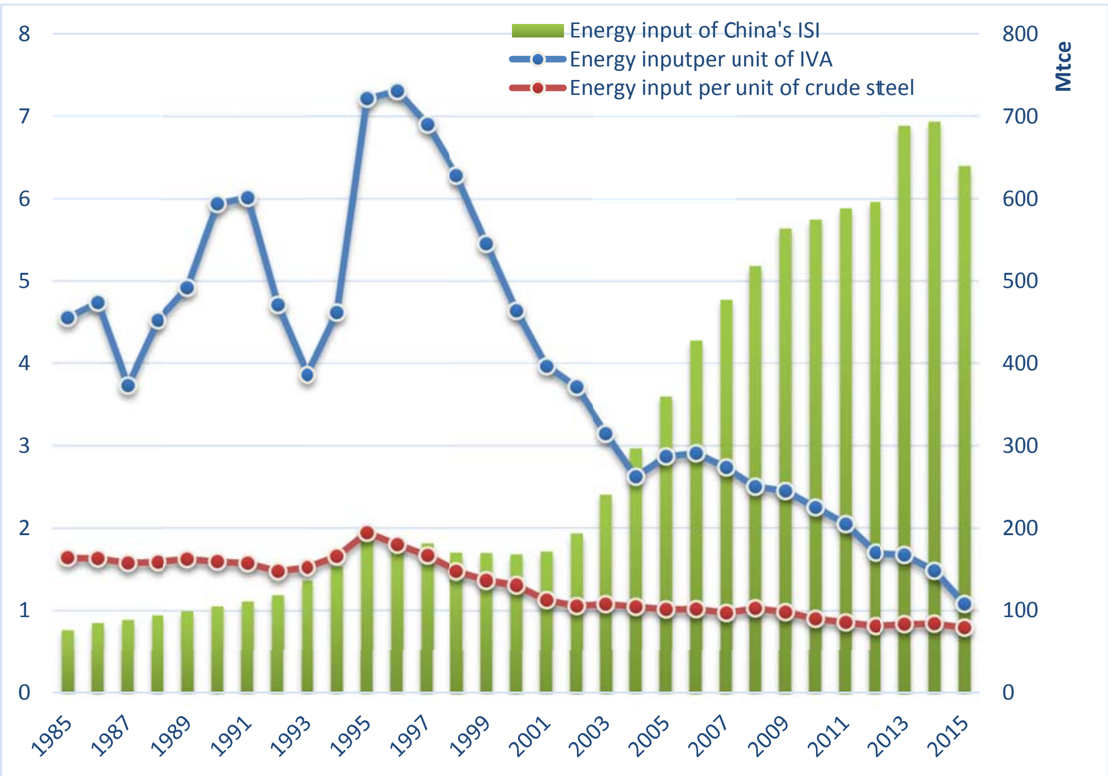

Figure 3 Changes of energy intensity in the ISI in China

Source: China Statistical Yearbook (China Statistics Press, 1986-2016).

From the above analysis, it is noticed that as the technical level in China's ISI improves, energy efficiency in this sector shows an increasing trend. However, due to the energy rebound effect, the improvement in energy efficiency may not give rise to a decrease on energy use, which can make the energy policies aiming at energy savings less effective. The rebound effect describes the phenomenon that energy efficiency can be improved by the use of new technologies; however, along with the new technologies and increased energy efficiency, industrial enterprises and residents may increase their consumption of energy resources (Khazzoom, 1987; Grubb, 1990; Wirl, 1997; Wang et al., 2012) (see figure 4). For iron & steel enterprises, improvement in energy efficiency means that less energy input achieves equivalent output and thus other inputs such as capital and labor will be replaced by energy (Wang and Lin, 2017). Whether technology-induced efficiency improvement could reduce energy consumption, it is strongly related to the effectiveness of energy policy.

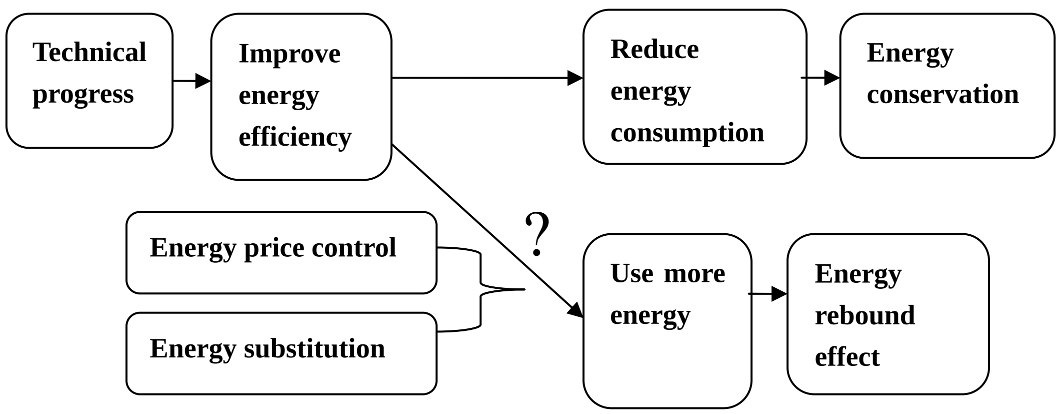

Figure 4 The relationship between technical progress and rebound effect

Therefore, the purpose of the paper is to evaluate the energy rebound effect in China's ISI, taking into consideration the energy price control and energy substitution.

The main contributions are comprised of three aspects: (1) a non-neutral-technical-progress trans-log cost function model is built to interpret the relationship between technical progress and rebound effect; (2) the price elasticities and energy substitution effect between energy and other input factors are evaluated; (3) the energy rebound effect in China's ISI is estimated using asymmetric price method, based on which the changes of rebound effect in each F~~f~~ive-year period are analyzed.

The rest part of the paper is structured as the following sections: Section 2 emphasizes on literature review. Section 3 describes the methodology for building an evaluation model to estimate the energy rebound effect. Section 4 presents variables and data sources. Section 5 shows model results and the corresponding analysis. Section 6 concludes this manuscript and give policy suggestions.

2. Literature review

The concept of energy rebound effect was initially introduced by Khazzoom (1987). After that, there were many researches focusing on theoretical analyses to give in-depth understanding of energy rebound effect, such as Greening et al. (2000) and Jin (2007). Based on Khazzoom (1987), improvements in energy efficiency caused by technical progress would promote energy conservation. However, the improved technical level, along with an increased operational efficiency of production equipment, would lead to a decrease in the corresponding production cost, thus encourage further economic development, and ultimately accelerate energy consuming. Improvement in energy efficiency could boost energy consumption in two ways: (1) through reducing the cost of energy consumption and thus encouraging producers to substitute energy for other production inputs; (2) through making the economy grows more rapidly, thus accelerating energy consumption. Whether energy conservation policies would meet the established goals depends largely on the rebound effect.

For empirical research on the topic, there are a variety of researches that analyze the energy rebound effect in various sectors of the economy. Roy (2000) estimated the technical efficiency promotes energy consumption in India and concluded that if there are no relative pricing policies, it is not feasible to inhibit the energy rebound effect in a developing country. Binswanger (2001) analyzed the influence of substitutability as well as the income effect on the rebound effect, and their empirical research concluded that the rebound effect of service sector was less than 25%. Bentzen (2004) evaluated the rebound effect of the manufacturing industry in the US using time series data. Results showed the rebound effect was around 24%. Hens et al. (2010) calculated the direct rebound effect of household heating and analyzed the effect of energy price on direct rebound using consumption data obtained from 964 households. Ghosh and Blackhurst (2014) built a household production model to study efficiency correlation and the rebound effect between residential and transportation sectors. Yu (2015) analyzed the energy rebound effect and sectoral shocks in the USA using CGE model. Freire-Gonzalez (2017) estimated the rebound effect in European Union countries and found that the rebound effects in most economies are lower than 100%.

As China's government has promulgated a series policies to save energy and control environment problem (Zhang et al., 2017), energy rebound effect is becoming a hot issue. In China, Zhou and Lin (2007) first conducted analysis regarding the rebound effect of China's energy consumption using macroeconomic time series between 1978 and 2004, and their results suggested the rebound effect fluctuated within the range of 30-80% from a macroeconomic perspective. By improving Zhou and Lin (2007)'s model, Lin and Liu (2012) concluded that the overall rebound effect in China's energy consumption during 1981-2009 is around 53.2%. Some studies focus on household consumption since price data in household sector is available in China. Yu et al. (2013) estimated both the direct rebound effect and indirect rebound effect of residential energy consumption in Beijing city. Lin and Liu (2012)'s research showed the energy rebound effect of China's passenger transport is 107.2%, which was defined as "back fire effect". Wang et al. (2014) studied the direct energy rebound effect on household electricity consumption in using panel co-integration and suggested the values of long-term and short-term energy rebound effect are 74% and 72%, respectively.

Econometric methodologies used for energy rebound effect estimation can be concluded as the following types. (1) The direct calculation methods: including OLS model (Greene, 1992; Wirl,1997), GLS model (González, 2010), instrumental variable method (IV) model (Nesbakken, 2001), 3SLS model (Small and Dender, 2005, Hymel et al. 2010) and SUR model (Wang et al. 2011). (2) CGE model: Allan et al. 2007; Wei, 2010; Yu et al., 2015. (3) Price elasticity model: Lin and Zhao (2016), Lin and Li (2014), Yang and Li (2017), etc. Among the three methods: the direct calculation method is based on the definition of rebound effect, but this method cannot reflect the connection of improving energy efficiency and energy price control; improving in electricity price is significantly driving industrial enterprise's energy efficiency to increase (Zhang, 2012). The CGE model can show the economic implication of the rebound effect, but fails to illustrate the reason of energy rebound. While the price elasticity or efficiency elasticity method is generally accepted, as it uses price elasticity to calculate the rebound effect, which can reflect not only the mechanism of the rebound effect but also the connections between technical progress, energy substitution and rebound effect.

Although the ISI is one of the most energy-consuming sectors, the studies analyzing the energy rebound effect in this sector are limited. Therefore, we try to estimate the energy rebound effect and the corresponding price elasticities in China's ISI, by building the model of trans-log cost function. Policy suggestions are provided for achieving energy conservation in industrial sectors.

3. Methodology

As energy price changes, iron & steel enterprises are likely to change the share of inputs (energy, capital and labor) in the production process. The price elasticities for these three input factors can be estimated, based on the three-input production function built as Eq.(1) and the trans-log cost function written as Eq.(2).

$$Y = f(A, E, K, L) \tag{1}$$

In Eq.(1), Y indicates total output of the iron & steel industry; E, K and L denote input factors of energy, capital and labor, respectively; while A indicates technical progress. In order to calculate price elasticities for these input factors, the industrial output and input factors are assumed to be exogenously given. The trans-log cost function and homogeneity restrictive conditions can be expressed as Eq. (2) and Eq (3):

$$\begin{aligned}\ln TC = &\frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m}\beta_{ij}\ln P_{it}\ln P_{jt} + \sum_{i=1}^{m}\beta_i \ln P_{it} + \beta_0 + \beta_t t + \frac{1}{2}\beta_{tt}t^2 + \beta_y \ln Y_t \\ &+ \frac{1}{2}\beta_{yy}(\ln Y_t)^2 + \sum_{i=1}^{m}\beta_{iy}\ln P_{it}\ln Y_t + \sum_{i=1}^{m}\beta_{it} t \ln P_{it} + \beta_{yt} t \ln Y_t\end{aligned} \tag{2}$$

$$\beta_{ij} = \beta_{ji} \quad \textit{for all } i \neq j$$

$$\sum_{i=1}^{m}\beta_i = 1, \sum_{j=1}^{m}\beta_{ij} = 0, \sum_{i=1}^{m}\beta_{iy} = 0, \sum_{i=1}^{m}\beta_{it} = 0, i, j = 1, \cdots, m \tag{3}$$

In Eq.(2), TC indicates the total cost; P_{it} or P_{jt} denoted the price of each input factor; i(j) = E, K, L denotes input factors of energy, capital and labor, respectively; t works as a time trend variable representing the level of technology.

According to the Shephard's lemma and combined with Eq. (2), the factor share equation for each input factor can be written as Eq. (4):

$$S_{factor} = \beta_{iy}\ln Y_t + \sum_{j=1}^{m}\beta_{ij}\ln P_{jt} + \beta_i + \beta_{it} t \tag{4}$$

Based on the above factor share equation, Allen proposed the equations of cross-price elasticity (CPE) and own-price elasticity (OPE), which can be expressed as Eq.5 and Eq.6, respectively.

$$\eta_{ij} = (\beta_{ij} + S_i S_j) / S_i \tag{5}$$

$$\eta_{ii} = (\beta_{ii} + S_i^2 - S_i) / S_i \tag{6}$$

Where, $S_i(S_j)$ is the cost share of the $i(j)th$ factor. η_{ij} indicates variations of factor i caused by fluctuation of the price of factor j, as a result, it reflects the substitution effect between capital, labor and energy. When technical level in iron &

steel production is improved, less energy is needed to produce the same amount of products; however, as the improved energy efficiency will make energy relatively cheaper than capital and labor, steel producers is likely to use more energy to substitute capital or labor, and thus lead to further energy consumption.

According to the definition of rebound effect, when technical progress happens, energy use efficiency will be improved, however; producers consume more energy than before. The consumption of energy can be evaluated by the own-price elasticity of the decreasing energy price and the substitution elasticities between energy and other inputs. Therefore, the decreasing trend of energy price should be separated first. Existing literature suggest that the asymmetric price method is widely adopted to separate energy price changes (Bentzen, 2004; Gately and Huntington, 2002; Adofo et al. 2013; Lin and Li, 2014). Based on the asymmetric price effect, changes in energy price can be decomposed into a decreasing energy price effect and an increasing energy price effect.

$$P_{e,t} = P_0 * P_{dec,t} * P_{inc,t} \tag{7}$$

$$P_{dec,t} = \Pi_{i=0}^{t} \min\left\{1, P_i / P_{i-1}\right\} \tag{8}$$

$$P_{inc,t} = \Pi_{i=0}^{t} \max\left\{1, P_i / P_{i-1}\right\} \tag{9}$$

According to Eq (7), energy price is decomposed into three components, P_0 denotes energy price in the initial year, $P_{dec,t}$ represents the decreasing trend of energy price change, and $P_{inc,t}$ represents the increasing trend of energy price change. Based on Eq (7-9), the energy cost share equation can be written as:

$$S_e = \hat{\beta_0} + \hat{\beta}_{e\_dec} \ln P_{dec} + \hat{\beta}_{e\_inc} \ln P_{inc} + \hat{\beta}_{e\_k} \ln P_k + \hat{\beta}_{e\_l} \ln P_l + \hat{\beta}_{e\_y} \ln Y + \hat{\beta}_{e\_t} t \tag{10}$$

Thus, the energy rebound effect can be estimated by:

$$RE = \eta_{ij\_dec} = (\beta^{\wedge}_{e\_dec} + S^2_e - S_e) / S_e \tag{11}$$

4. Data sources and processing

Based on the model before, variables of industrial output, industrial input factors and the prices of input factors in China's ISI are necessary for empirical analysis (see Table 1). The time interval of data is 1985-2015. In order to conduct comparable analysis, all nominal variables have been converted to the 1985 price level.

Table 1 Data sample for each variable

<table>
<tr><td colspan="3">Variable declaration</td><td>Size</td><td>Mean-Value</td><td>Min-value</td><td>Max-value</td></tr>
<tr><td colspan="2">Production output （billion）</td><td>Y</td><td>31</td><td>126.83</td><td>16.78</td><td>591.06</td></tr>
<tr><td rowspan="3">Input factors</td><td>Energy (Mtce)</td><td>E</td><td>31</td><td>295.50</td><td>76.40</td><td>693.42</td></tr>
<tr><td>Capital （billion）</td><td>K</td><td>31</td><td>19.18</td><td>3.46</td><td>65.65</td></tr>
<tr><td>Labor input (thousand)</td><td>L</td><td>31</td><td>3087.35</td><td>2430</td><td>4220.70</td></tr>
<tr><td rowspan="3">Prices of input factors</td><td>Labor price</td><td>P_l</td><td>31</td><td>366.67</td><td>100.00</td><td>1059.68</td></tr>
<tr><td>Capital price</td><td>P_k</td><td>31</td><td>105.55</td><td>100.00</td><td>113.40</td></tr>
<tr><td>Energy price</td><td>P_e</td><td>31</td><td>141.29</td><td>74.35</td><td>191.76</td></tr>
</table>

4.1 Variables of industrial output and input factors

(1) Industrial value added (IVA): industrial output indicators include industrial products, gross output value and IVA. For ISI, there are variety types of industrial products, as a result, the value of production is difficult to be quantified. The indicator of gross output value takes into account also the value of intermediate products, which does not meet the definition of output in the ISI in this paper. Therefore, IVA is

adopted to represent output in this sector and the statistical data of IVA is extracted from the CEIC database (CEIC, 2016).

(2) Labor input: number of employees, collected from '*China Statistical Yearbook*' (China Statistics Press, 1986-2012), is used to measure the labor input. Though the statistical data of employees in the ISI during 1999-2002 is missing, it can be estimated through another statistical indicators, the overall labor productivity, which is the result of IVA divided by the number of employees.

(3) Capital input: in '*China Statistical Yearbook*', there are two statistic indicators related to the capital input, which are the original value and net value of fixed asset. However, both of them are representing the purchase value of capital goods, not the real capital input. In order to evaluate the real capital input in the ISI, we need to estimate the capital stock for each year. Therefore, like Zhang et al.(2004), Wang (2004) and Shan (2008), the capital stock during 1985-2015 are estimated by perpetual inventory method (PIM) in this paper.

(4) Energy input: in order to obtain the total energy input, the input of different energy sources (coal, coke, oil, electricity, etc.) is added together by converting them into the unit of coal equivalent. Both data of energy consumption and the corresponding converting coefficients are obtained from '*China Energy Statistical Yearbook*'. In order to calculate energy input cost, similar to Cho et al. (2004), we divide energy input into three kinds, including coal-related energy, oil-related energy and electricity. The input of nature gas is ignored here because of its small proportion (0.42%) in the energy input structure of China's ISI (Xie et al., 2016).

4.2 Variables of factor prices

(1) Labor price: real wages show the value of labors' real income adjusted for inflation, which can be used to represent labor price. Due to data availability, the indicator of overall wage of the manufacturing industry is adopted to indicate the level of labor price in the ISI, which is available in the CEIC database (CEIC, 2016).

(2) Capital price: the real price of capital is the real return on fixed asset investment. Therefore, investment return can be expressed as the nominal interest rate $r(t)$ plus depreciation rate $\delta(t)$, and then be converted into actual interest rate by minus the inflation rate $\pi(t)$. All data needed in the calculation of capital price are obtained from the CEIC database (CEIC, 2016) and the calculation process is shown in Eq. (13).

$$P_{k,t} = r(t) + \delta(t) - \pi(t) \tag{13}$$

(3) Energy price: the prices of variety final energy sources. The prices of the above-mentioned three energy sources are not comparable as different types of energy are measured by different physical units. In order to evaluate the real energy price, the market prices of all energy kinds are needed. Then the time varying weight $\xi_{i,t}$ is the energy input structure in China's ISI. Therefore, energy price in the ISI can be estimated by Eq.(14):

$$P_{e,t} = \sum_i \xi_{i,t} * p_{i,t} \quad i \in \{coal, oil, electricity\} \tag{14}$$

5. Empirical analysis

5.1 Estimated results on price elasticities

In order to get the price elasticity for each input factor, the parameters in factor share equation (Eq. 4) should be estimated first. As the factor share equations of energy, capital and labor are influenced by each other, the three equations are estimated by system estimation method. The results of the estimated coefficients are shown in Table 2. The conventional R^2 is 0.90 in the energy share equation, 0.89 in the capital share equation and 0.91 in the labor share equation, respectively. In Table 2, the sign of each parameter indicates that the model is in accordance with economic reality. The value of t suggests the significance of these parameters at the 5% level.

Table 2 The estimation results for factor share equation

Variables	Coefficients	Estimations	Standard Error	t-value	Probability
$Constent\_(S_e)$	β_0	-0.20	0.10	-2.04	0.04
$\ln P_e\_(S_e)$	β_{1_e}	0.22	0.03	8.41	0.00
$\ln P_k\_(S_e)$	β_{2_k}	-0.09	0.03	-2.67	0.01
$\ln Y\_(S_e)$	β_{3_Y}	0.06	0.02	3.24	0.00
$t\_(S_e)$	β_{4_t}	-0.01	0.00	-2.59	0.01
$Constent\_(S_k)$	β_5	0.57	0.11	5.03	0.00
$\ln P_k\_(S_k)$	β_{6_k}	0.07	0.05	1.52	0.10
$\ln Y\_(S_k)$	β_{7_Y}	-0.04	0.02	-1.65	0.10
$t\_(S_k)$	β_{8_t}	0.02	0.00	4.94	0.00
$\ln P_l\_(S_l)$	β_{9_l}	0.12	0.02	6.86	0.00

$$S_e = \beta_0 + \beta_{1\_e} \ln P_e + \beta_{2\_k} * \ln P_k - (\beta_{1\_e} + \beta_{2\_k}) * \ln P_l + \beta_{3\_Y} * \ln Y + \beta_{4\_t} * t$$

$$S_k = \beta_5 + \beta_{2\_k} * \ln P_e + \beta_{6\_k} * \ln P_k - (\beta_{2\_k} + \beta_{6\_k}) * \ln P_l + \beta_{7\_Y} * \ln Y + \beta_{8\_t} * t$$

$$S_l = 1-(\beta_0+\beta_5)-(\beta_{1\_e}+\beta_{2\_k})*\ln P_e-(\beta_{2\_k}+\beta_{6\_k})*\ln P_k+\beta_{9\_l}*\ln P_l$$
$$-(\beta_{3\_Y}+\beta_{7\_Y})*\ln Y-(\beta_{4\_t}+\beta_{8\_t})*t$$

Based on the above results, the cross-price elasticity (η_{ij}) and own-price elasticity (η_{ii}) can be calculated according to Eq. (5-6). However, the average cost share of energy, capital and labor should be calculated first. According to Lin and Li (2004), the average cost share means the average proportion of the cost of each input factor in total input cost over the research periods (31 years in this paper), which can be calculated by Eq. (15).

$$\overline{S}_i = \frac{\sum_{t=1}^{31}(P_{it}*Q_{it})/(\sum_{i=k,e,l}P_{it}*Q_{it})}{31} \tag{15}$$

Where i indicates energy, capital and labor; t indicates the year; P_{it} and Q_{it} indicate the price and quantity of input factor, respectively. The obtained result for the average cost share of energy, capital and labor is 0.596, 0.214 and 0.189, respectively. As a typical energy intensive manufacturing sector, the average share of energy in the ISI approximates the average energy share in the manufacturing industry, which is about 0.53 based on the research by Dong et al. (2012). The results are shown in Table 3.

Table 3 Elasticities of cross-price and own price for input factors in the ISI

η_{ij}	L	E	K
L	-0.19	0.12	0.31
E	0.04	-0.03	0.07
K	0.27	0.19	-0.46

The following conclusions are drawn from Table 3. (1) The own price elasticities of energy, capital and labor are -0.03, -0.46, and -0.19, respectively. The results indicate that a change in price of one input factor would bring about influence to input quantity in the adverse direction. (2) The price elasticity of energy is relatively small (-0.03), compared to that of labor and capital. The main reason is that the prices of energy in China is regulated and maintained at a low level. Therefore, the rigid energy price lead to small price elasticity. (3) The estimated energy-capital elasticity and energy-labor elasticity are positive, which implies a substitutable relationship between energy and other input factors. When energy price decreases, the iron & steel enterprise would be likely to reduce their capital and labor inputs and use more energy.

5.2 The energy rebound effect in the ISI in China

Based on the definition of energy rebound effect, a decreasing energy price can bring about more energy use and further rebound effect. In order to evaluate the energy rebound effect in the ISI, energy price is decomposed into increasing energy price and decreasing energy price based on symmetric price effect as stated in Eq.(7)-(9), which is shown in Fig. (4).

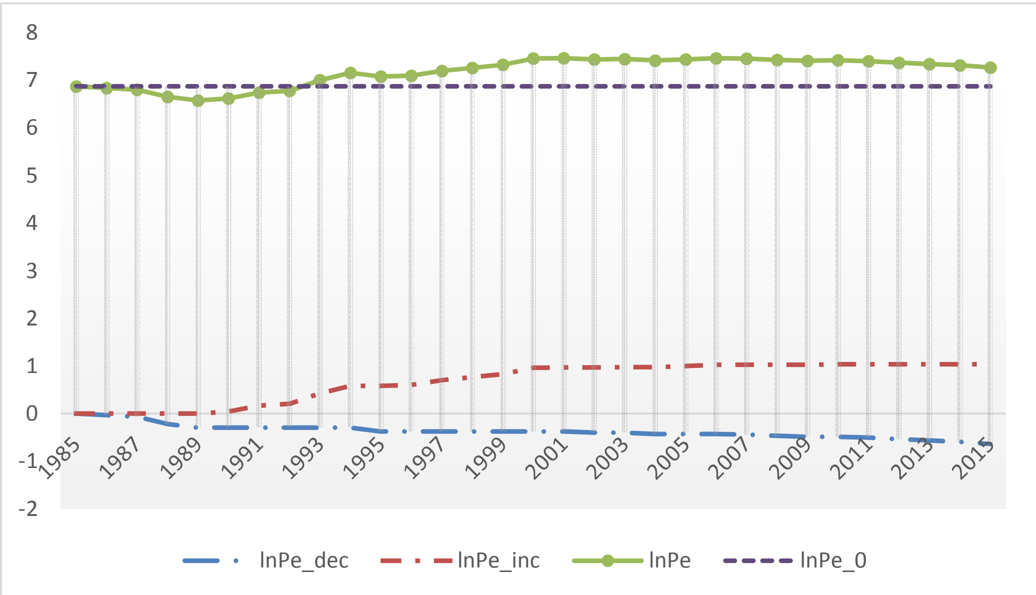

Figure 4. Decomposition of the energy price in China from 1985 to 2015

By decomposing the energy price, we re-estimate the energy input share equation in Eq.(10), with results given in Table 4. Then on the basis of the definition of energy rebound effect and substitution effect, energy rebound effect can be calculated by the own price elasticity of decreasing energy price.

Table 4 Evaluation of energy input share equation with decomposed energy price

	coefficient	Std. Error	T-value	P
α_i	2.36	0.67	3.52	0.00
$\ln P_e\_dec$	-0.21	0.19	-1.08	0.00
$\ln P_e\_inc$	0.45	0.07	6.63	0.00
$\ln P_k$	-0.26	0.06	-4.45	0.00
$\ln P_l$	-0.32	0.13	-2.45	0.02
$\ln Y$	0.18	0.03	5.70	0.00
t	-0.01	0.01	-0.79	0.44
Adj-R^2	0.92			
Own price elasticity				
$\ln P_e\_dec$	-0.74			
$\ln P_e\_inc$	0.33			

Table 4 suggests most parameters are significant at the 5% level. The adjusted-R-squared value is 0.92, which implies a high fitness of the estimated coefficients. According to the model results, the energy rebound effect in the ISI is estimated to be as high as 74%. The result means that when energy efficiency is improved through technical progress, 74% of expected energy-saving would be offset due to the decreasing energy prices. Therefore, although China's ISI is experiencing a rapid technical progress, the existence of the low energy prices is encouraging the iron & steel enterprises to input more energy resources rather than capital or labor, and thus limit the impact of technical progress on energy saving and carbon reducing. This conclusion is in accordance with Lin and Li (2014)'s estimation for heavy industries, which is around 74.3% over 1980-2010. In addition, the overall energy rebound effect was estimated to be 88.42% over 1998-2011 by (Li et al., 2015) in the entire industrial sector; and 90.75% over 2006-2012 by (Lin and Tian, 2017) in those energy intensive industries in China.

Table 5 Energy rebound effect in the ISI during each ~~F~~five-year period

Period	Year	Energy rebound effect
7th Five-year Plan	1986 to 1990	83.26%
8th Five-year Plan	1991 to 1995	72.75%
9th Five-year Plan	1996 to 2000	69.32%
10th Five-year Plan	2001 to 2005	65.27%
11th Five-year Plan	2006 to 2010	68.74%
12th Five-year Plan	2011 to 2015	84.53%

To understand the changing trend, we further calculate the energy rebound effect during each F~~f~~ive-year period. At first, the energy rebound effect maintained a continuous declination and dropped from 83.26% during the 7th Five-year period, to 65.27% during the 10th Five-year period. The decreasing energy rebound effect means that smaller proportion of expected energy saving is offset and the influence of technical improvement on energy saving is strengthened. During the “10th Five-Year plan” period, the production of crude steel has increased by 174.2%. In the meanwhile, energy consumption in the ISI increased only by 120%. The index of energy consumption per ton steel in key iron & steel enterprises[1] fell from 876 kilogram of coal equivalents per ton (kgce/t) to 741 kgce/t, indicating a decline of 15.4% (Zhang et al. 2013). Therefore, empirical data confirm that the improvement in energy efficiency due to technology upgrade reduced energy use.

During the “11th Five-year plan” period, energy rebound effect increased a bit but still kept at a low level (68.7%). In this period, China’s government proposed energy intensity and emission intensity target: energy consumption and carbon emission per GDP should be reduced by 20% and 10% respectively by 2010. The rigid target induced substantial improve in energy efficiency of China’s ISI. T Two major specific energy saving policies were implemented in China’s ISI at that period. One was the policy of reducing outdated production capacity. During the “11th Five-year plan” period, a total of 122.72 million tons of iron capacity and 72.24 million tons of steel

1 The technical level of key ISI enterprises can reflect the main level of China’s ISI, whose steel production accounted for about 80% of total steel production in China.

capacity had been cut, which reduced energy use in each producing process. The other was the promotion of advanced energy-saving technologies. The penetration of dry Top Gas Pressure Energy Recovery Turbine (TRT) and recovery technology of converter gas reached more than 50%, and some large enterprises established energy management centers, which significantly promoted energy saving in the ISI. However, from the perspective of rebound effect, energy prices were still regulated at a low level during the period, therefore iron & steel enterprises preferred to input energy rather than other input factors (capital and labor); at the same time, financial crisis inhibited normal activities in financial market, which had positive effect on the substitution between capital and energy. Therefore, although the above mentioned energy-saving policies were carried out, energy rebound effect had increased a bit during the period.

It is worthy of mentioning that the rebound effect during the 12th Five-year was higher than that during the 11th Five-year. In the 12th Five-year Plan, China's government also proposed the numerical reducing target of energy consumption and carbon emission per GDP, which 16% and 17% respectively by 2015. However, improving in energy efficiency do not mean actual energy saving. In China's ISI, compared with the 11th Five-year, the energy rebound effect increased, which means that iron & steel enterprise input more energy resources. The input decisions of iron & steel enterprise rely on prices of input factors. Coal-related energies have been the dominant energy inputs in China's ISI, which account for 80% of energy input structure (Wang and Lin, 2017). Since 2006, the price of coal products gradually moved towards the direction of marketization. Compared with the regulated prices in the past, coal prices began to fluctuate. The rebound effect showed an increase during the "12th Five-Year plan" mainly due to the significant drop in market coal prices. Low market coal price lead to more input of coal-related energy and less energy conservation. Therefore, coal price is the main reason for high energy rebound effect. However, China's market coal prices do not include external cost, especially the environment cost of coal combustion. If the external cost included, coal price should be higher and rebound effect could be reduced.

To sum up, the rebound effect in the ISI maintained a downward trend until the 11th Five-year period, since when it started to show an upward trend. Because higher energy rebound effect means less energy saving, therefore the upward trend of rebound effect should be controlled. Now, 3 years have passed since the 13th Five-year, and the ISI is facing a more challenging energy input restriction. In the 13th Five-year Plan, Chinese government has proposed not only the numerical reducing target of energy consumption per GDP (15%), but also the total amount control of energy consumption (5000 Mtce). Compared with the 12th Five-year, the energy efficiency in the ISI has been improved by applying energy saving technologies; in the meanwhile, the target of total amount control has enforced the iron & steel enterprises to either reduce energy inputs or substitute energy with other input factors (capital and labor), to ensure the actual energy saving. Together with the market-oriented energy prices, energy rebound effect is expected to be stabilized within a certain range.~~Now, 3 years of 13th Five-year passes, ISI is facing more strict energy input restriction. In 13th Five-year Plan, China's government not only proposed the numerical reducing target of energy consumption per GDP (15%), but also total amount control of energy consumption (5000 Mtce). Compared with 12th Five-year, energy saving technologies improve energy efficiency; at the same time, the target of total amount control enforce iron & steel enterprise to reduce energy input, substitute energy with other input factor (capital and labor), and ensure actual energy saving. Together with more market-oriented energy price, energy rebound effect can be controlled.~~

6. Conclusion and policy suggestions

As reducing energy consumption and producing in a cleaner way are more and more important in heavy industrial sectors, China's government implemented Energy Saving and Emission Reduction policy since 2005. After that, the government proposed numerical target in every Five-year Plan. However, actual energy saving do be affected by these energy saving policies, but also relied on energy price policy and rebound effect. Therefore, the relationship between technical progress and energy rebound effect has become a valuable research issue. In order to conduct empirical analysis, a trans-log cost function model is built in this research to evaluate the price elasticities of production inputs and estimate the energy rebound effect in the ISI over 1985-2015. Main conclusions include: (1) The price elasticities of input factors are negative; (2) Energy/ capital and energy/labor show substitute relationships; (3) The average energy rebound effect in the ISI is as high as 73.88%; (4) The energy rebound effect shows a downward trend before the 11^{th} Five-year period and then a upward trend after that.

As the existence of high energy rebound effect in China's ISI, energy policies regarding energy conservation should be focus on lowering energy rebound effect. Based on the economic model we built and the empirical conclusions obtained, some policy suggestions are given as follows:

Firstly, accelerating the implementation of more energy-saving technologies. The changing trends of energy rebound effect indicate that technical progress do bring energy saving. Thus, improving technical level will become an important measure to reduce rebound effect. As technical innovation needs substantial initial investment, government should increase financial support for energy innovation and clean energy technologies. At the same time, the implementation of energy-saving technologies cannot be ignored, and government should also help the enterprises to cultivate employees and promote further applications.

Secondly, reducing energy price regulation. Although energy price elasticity is small (-0.032), the negative price elasticity means that price transmission mechanism in China's ISI is effective. As the price of different energy sources (coal, oil, and electricity) increases, energy consumption will be reduced. More effort is needed to promote mechanism reform for energy price towards marketization. At present, although coal price in China has been decided by the market, there are still high level of government regulation in oil and electricity prices. Electricity input is particularly important for iron & steel production. Deregulation in electricity price can lead to an increase in industrial electricity price, and thus a reduction in electricity input.

Thirdly, cutting down energy subsidies. The existence of high rebound effect means that the decreasing price of energy products and services make it cheaper than labor and capital, and lead to an increase in energy demand. However, most energy enterprises in China are state-owned. The monopoly of state-owned energy resources as well as administrative pricing lead to the retaining of fossil energy prices at a low level. In addition, there is substantial government subsidies in China's energy products. Energy subsidy policy will further lower the prices of energy products and promote the rebound effect, leading to a higher energy consumption and an environment deterioration. Therefore, fossil energy price reform and subsidy reform are crucial to mitigating energy rebound effect.

Fourthly, promoting substitutions between capital/labor and energy resources. The substitutive relation exists between energy and other input factors, which enables the attempt of achieving energy conservation through energy substitution. Along with the government controlled energy prices, iron & steel enterprise are likely to use more energy to substitute capital and labor inputs. The steel output has increased rapidly but with tremendous energy consumption. As a result, policies should aim at substitutions in the adverse direction, by using more capital or labor to substitute energy input. For example, government can promote public investment in energy conservation, carbon reduction and cleaner energy sources; government can also increase expenditure in human resource investment; and enterprises should update their equipment to use less energy. Besides substitutions between capital/labor and energy resources, inter-fuel substitutions are also a potential solution. For example, promoting clean energy policies and introducing more electricity generation from renewable sources through energy storage (Xie et al., 2018).

To sum up, although China's energy prices are getting market-oriented, energy prices in China are still regulated by the government and stated owned companies, and the state controlled prices inhibit substitutions between input factors, finally lead to more energy consumption. Therefore, implementation of government's Energy Saving and Emission Reduction policy rely on lowering rebound effect; lowering rebound effect should combine the promotion of energy-saving technologies with reducing energy price regulation, cutting down energy subsidies and promoting substitution among input factors.

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